AMERICAN SOCIETY OF CIVIL ENGINEERS.

>-●-<

INTER-OCEANIC
CANAL PROJECTS.

>-●-<

By A. G. MENOCAL, Member Am. Soc. C. E.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

————▸◂◃————

TRANSACTIONS.

————▸◆◂————

CLXXXVIII.

————

INTER-OCEANIC CANAL PROJECTS,

BY A. G. MENOCAL, C. E., Member of the Society.

READ NOVEMBER 19, 1879.

————

The object of the present paper is to present for discussion before the Society of Civil Engineers a question which is now attracting much public interest through the press of the country, and which deserves the most attentive consideration by the engineer, on account of its magnitude, the engineering difficulties involved in the solution of the problem, and the great interest the world at large has always shown, and will continue to show in the execution of the work.

It is evident that the American Isthmus has been sufficiently explored by the U. S. Surveying expeditions, and by private parties interested in opening a water passage, between the Atlantic and Pacific Oceans, to enable us to determine the difficulties that would have to be met in the construction of a ship canal at the several places pointed out as presenting favorable indications for execution, and on a careful examination of all the available data, the question seems to have narrowed down to Panama and Nicaragua as the only places where the work can be successfully carried out. It is to the discussion of the most prominent features of these two routes, and their relative advantages and disadvantages that I will confine myself.

Three projects for a canal at Panama have been seriously suggested and estimated upon, two at the level of the ocean, and one with locks. Of the first two, the one extending from the Bay of Colon to the Bay of

Panama has been devised by Lieuts. Wyse and Reclues of the French Navy, and lately advocated by M. de Lesseps, the successful promoter of the Suez Canal ; and the other connecting the Bay of San Blas, on the Atlantic, with the Rio Bayano in the Bay of Panama, was first partially surveyed by Messrs. MacDougal and Sweet, in the interest of Mr. Kelly, and subsequently re-examined by Commander Selfridge, U. S. N., in 1871, and Lieut. Wyse, in 1878.

The project for a canal, with locks, via Panama, was carefully studied, and the line actually located by the U. S. Surveying Expedition, under Commander E. P. Lull, U. S. N., in 1875, of which the writer was the chief engineer.

LIEUT. WYSE'S PLAN.

This project was first presented for discussion before the International Canal Congress, assembled at Paris, on the 15th of May of the present year, and is fully described by the author in his report to the president of the " Société du Canal Interoceanique," dated April 4, 1879. As originally projected it consisted of a thorough cut at the level of the oceans, 73 200 metres (45.5 miles) in length, 20 metres (65.6 feet) wide. and 8.5 metres (27.88 feet) depth of water, with a tunnel 72.20 metres (4.8 miles) long. The river Chagres, as well as the Rio Grande, and their tributaries to the number of 22, are to be received into the canal ; the only provision made to ameliorate the effect of such an enormous volume of water is 191 000 cubic metres of excavation, in the beds of the streams at the several points of junction with the canal. The estimated cost of the work, as given by Lieut. Wyse, in his report, is 475 000 000 francs, or $95 000 000. This line is not one of actual location, but was traced on a map of the isthmus, between Colon and Panama, constructed from such information as could be obtained from the maps of the rail-road and the survey of Mr. Garella, made in 1843 for a canal, with locks, on a location other than that adopted by Lieut. Wyse. The elevations of the ground given in the profile were also obtained, as near as practicable, from the same source of information, and the figures are, therefore, to say the least, a rough representation of the natural conditions.

This project was considered impracticable by the Technical Commission of the Paris Congress The sudden and high floods to which the turbulent river Chagres, and its tributaries, are subject in the rainy season, and the disadvantages under which those streams would have to be taken into the canal, on account of the elevation of their beds above

the sea, the proposed level of the canal, together with the current that would be produced in the canal by the rise and fall of the tide in the Bay of Panama (the spring tides amounting to 22 feet, would form such impediments to navigation, and so many serious difficulties, and doubtful elements in the execution and permanency of the work, that the plan had either to be modified, or abandoned altogether.

A sub-committee composed of the following distinguished engineers, viz., Messrs. Ruelle, Cotard, Couvreux, Favre, de Garay, Laroche, Lavalley and Lepinay were appointed to estimate on the probable cost of the tunnel designed by Lieut. Wyse. They reported that, supposing the work free from water, its probable cost would be about 38 500 francs per lineal metre, or $59 444 000 for the length of tunnel proposed, and with 25 per cent. added for contingencies, $74 305 000. But if the work had to be done under water, as it was thought would be the case in that portion of the excavation below the level of the sea, then the above estimate would be insufficient, and although the committee could not, in that event, arrive at the approximate cost, it was of the opinion that the expense would be increased by at least 100 000 000 francs or $20 000 000.

To meet these objections Lieuts. Wyse and Reclues submitted several plans, more or less feasible, from which the following modifications to the original plan were accepted and estimated upon. A tide lock at the Pacific terminus to keep the surface of the water in the canal at the mean level of the Atlantic ; an open cut in place of the tunnel ; and new channels to carry to the ocean the waters of the river Chagres, and its tributaries, from Matachin to the sea, independent of the canal, which should be kept entirely free from all surface drainage.

These modifications were considered as an improvement on the first plan; but the engineers differed widely as to the methods of execution and the practicability of the works proposed, at least, in a commercial sense.

The above-named engineers, on consultation with the sub-committee on locks and profiles, adopted uniform cross-sections and prices per unit of work for all the projects submitted to the congress, and the modified project was estimated according to the amount of work computed by Lieut, Wyse at $208 800 000, exclusive of the indemnification to the Panama Railroad.

The committee remarked in their report that such a sum had been obtained by applying the adopted prices for labor and material to the

quantities of work furnished them, increased by the sum of $8,400,000 named by the Committee on locks, as required, in its estimation for the canalization of the Chagres and its tributaries and necessary accessories, and added that the committee was of the opinion "that the execution of such works as the long, open cut proposed with a maximum depth of 321 feet above the surface of the water, and the construction of a new channel for the Chagres, the stability of which would not be assured, are subject to so many contingencies and difficulties that it was not possible to arrive at an estimate of their probable cost." The competency of the engineers hereinbefore named as composing that committee cannot be doubted; they are men of high established reputation for integrity and professional experience, and their figures and opinions are entitled to full consideration.

I have made careful computations with the object of ascertaining the amount of excavation required for the open cut proposed, and in order to arrive at as close an approximation of the cubical contents as the data at hand would permit, the profile of the route submitted to the Paris Congress by Lieut. Wyse, has been altered by the substitution of the line of actual location of the United States Surveying Expedition, from the Chagres river to the Rio Grande, in lieu of the defective profile of Lieut. Wyse.

It should be stated, however, that the length of the line has not been changed, and that by the profile adopted I have been able to base the computations on an elevation of the ground taken at every hundred feet between those points, and that the dividing ridge is crossed at an elevation of 294.7 feet above mean level of the sea, instead of 321.4 feet as given in Lieut. Wyse's profile. From Colon to the River Chagres, at Matachin, and from the Rio Grande to Panama, no alterations have been made, and the depths of the excavation have been taken from that profile. For the sake of comparison the computations have been made both according to the cross-sections proposed for the Nicaragua and Panama canals, with locks, and that recommended by the Committee on Locks at the Paris Congress.

The following are the results obtained, viz.:

1st. With the cross-sections adopted for the Nicaragua canal:

Excavation in rock above the level of the sea 61 329 477

Excavation in rock below the level of the sea 14 111 806

Total rock cub. yds......................... 75 441 283

Excavation in earth above the level of the sea................ 15 904 339
Excavation in earth below the level of the sea............... 7 046 970

Total earth cub. yds......................... 22 951 309
Grand total of excavation in earth and rock, cubic yards. 98 392 592

Besides this amount, there will be required no less than 1 800 000 cubic yards of rock excavation under water in the bays of Colon and Panama.

2nd. With the cross-section recommended by the Paris Congress:
Excavation in rock above the level of the sea 38 821 559
Excavation in rock below the level of the sea 11 741 022

Total rock, cub. yds......................... 50 562 581
Excavation in earth above the level of the sea............... 14 694 916
Excavation in earth below the level of the sea............... 8 667 733

Total earth excavation cub. yds............... 23 362 649
Grand total of excavation in rock and earth................ 73 925 230

Or cub. metres.............................. 56 183 174

Which is 10 000 000 cubic metres in excess of the total amount of excavation estimated by Lieut. Wyse for the Paris Congress, on the same cross-section. The amount of rock and earth have been computed according to the geological profile submitted by Lieut. Wyse. It will be observed that the total cube of excavation required with the cross-section proposed by the Paris Congress, is about 25 per cent less than the amount obtained by adopting the cross-section proposed for the canal by Nicaragua. This is due to the insufficiency of the slopes for rock allowed by the Congress, viz : a vertical cut below and two metres above the water line, and an inclination of one-tenth above that point to the top of the rock. On the Nicaragua route one-half horizontal to one vertical, from the bottom of the canal to ten feet above the water, and one-fourth horizontal to one vertical above that point to the top of the rock, were considered necessary to obtain the permanency of the works, and they were so adopted throughout the line. The water prism for the canal in rock proposed for the Nicaragua line is 2 418 square feet ; that recommended by the Congress is 2 012 square feet. Nevertheless, it has been repeatedly stated by the friends of the Panama scheme that the

dimensions proposed for the Nicaragua route are insufficient for a ship canal, and that to this fact is due the large difference in the estimated cost of the two routes. It is well known to those informed of the variable geological formation of the isthmus, as observed in the digging of wells, excavations for railroads, gold and siver mines, and other works, that vertical cuts and slopes with an inclination of one horizontal to ten vertical are impracticable for the proposed work with a total length of continuous deep cut of 41⅓ miles, with an extreme depth of 322.5 feet above the bottom of the canal, and a mean depth of 174 feet for a distance of ten miles.

The amount of excavation herein given is exclusive of what may be found necessary to provide a new channel for the river Chagres and its tributaries from Matachin to the sea, a distance of 28 miles, as recommended by the Congress. No data has been obtained to enable us to arrive at an approximate cost of that work, estimated by the Congress at $3 400 000. The engineer may, however, appreciate the magnitude of that undertaking from the fact that the river Chagres, at Matachin, the point of its confluence with the canal, rises about 36 feet in times of flood; that the bed of the river is about 40 feet above the level of the sea, and has an inclination of 4½ feet per mile for a distance of 12 miles above that point. That the channel attains a width, in times of flood, of 1 500 or more feet, a sectional area of 15 000 square feet, a current of 7 miles an hour, and a discharge of about 160 000 cubic feet per second. The inclination of the bed decreases considerably below Matachin, and as its volume is materially swelled by the addition of affluents with large flow, the sectional area of the new channel will have to be increased in proportion. Below Matachin the river, for a distance of 10 miles, runs in a narrow valley confined by high precipitous hills, approaching from both sides. This valley is to be occupied by the canal, the width of which, at the top of excavation, will be about 500 feet. The new channel for the river will, therefore, have to be cut through the high hills on the north, and protected across the narrow valleys by heavy embankments, and, in some cases, masonry walls. Similar difficulties, but on a smaller scale, will have to be met on the south side of the canal in canalizing the river Trinidad and other large streams, tributaries to the Chagres from that side.

The difficulties and contingencies involved in the execution of such works, considering the location, climate, rainfall, etc., cannot be approx-

imately estimated with our present information.   Their stability, if ever completed, could not be assured, as they will be constantly menaced with total destruction by the periodical floods of the rivers.

Canals with Locks from Colon to Panama.

In 1875 the Government of the United States, at the request of the Commission appointed by the President to examine the different surveys made for an Inter-Oceanic Canal, and to report as to the line possessing the greatest advantages, sent out an expedition to ascertain the practicability of a canal, with or without locks, across the Isthmus of Panama.   In a preliminary examination of the route, it was observed that the high water marks of the river Chagres, in the vicinity of Matachin, disclosed the fact that the river was subject to freshets, which raised its surface to no less than 36 feet above its level in the dry season, which latter was 42 feet above the sea.   All idea of a canal without locks, or of utilizing the bed of the river for ship navigation, was therefore abandoned, and attention was directed to the location of a canal with locks that would cross the river at such an elevation as would give a free flow underneath to the highest floods.   The summit level of the canal was, on that account, fixed at an elevation of 123¾ feet above the mean level of the sea, as follows:

Elevation of highest water mark	77.70
Rise of arch	14.05
Thickness of arch	6.00
Depth of water in the canal	26.00
Elevation of summit level, feet	123.75

The river is proposed to be crossed by means of an aqueduct having 12 spans of 90 feet each, 1 900 feet extreme length, 65 feet wide and 26 feet deep.

The water to supply the canal will have to be obtained from the upper Chagres by means of a feeder 10¼ miles long, and involving seven tunnels with an aggregate length of 13 700 feet, and two siphons of 4 530 feet and 12 000 feet in length, respectively.

Careful gauges of the river Chagres, on the 15th of March, 1875, showed the discharge, at the point the feeder leaves the river, to be 55 900 800 cubic feet per day : an amount of water sufficiently large to supply the canal with 80 lockfulls per day, and to amply provide for evaporation, leakage and filtration.   In the month of April of the follow-

ing year, in passing across the Isthmus, I had occasion to observe that the river was lower, by at least one-third than at the time when the gauges were taken the previous year. Should my estimate be correct, it would evidently show that the supply, to say the least, could not be relied on at all times.

The line was carefully located from the Atlantic to the Pacific, developing an extreme length of 41¼ miles. The dividing ridge was crossed at an elevation of 294'.7 above mean half tide, giving an extreme depth of excavation of 171', plus the depth of water in the canal.

One tide lock is proposed in the Bay of Panama, and 24 lift locks, 12 on each side, of 10.3 feet lift each. The latter were located at those points offering the greatest facilities for construction, with a saving in the excavations. The form and dimensions of the cross sections for excavation in earth and rock, as well as the prices adopted, were for purposes of comparison exactly the same as had been recommended for the Nicaragua route. The estimated cost, including the necessary improvements in the bays of Colon and Panama, was found, on carefully made computations to be $94 511 360. Of this amount, $18 331 343 are estimated for the construction of 16 culverts and the necessary side drains to dispose of the surface drainage independent of the canal. The disadvantages of this route are : the length of tunneling and siphon required for the feeder, a doubtful supply of water, an aqueduct 1 900 feet long, swamp lands to be traversed by the canal, large mean annual rain fall of 124 inches, and total lack of building material of all kinds fit for the construction of the works recommended. The advantages are : short route from sea to sea, and fair harbors on either side. The railroad, in close proximity to the projected line, is a favorable condition, provided that its owners are willing to give up their franchise for all purposes at the cost of construction or a reasonable consideration, upon which I will not venture an opinion.

THE SAN BLAS ROUTE.

This is well known to be the shortest route between the Atlantic and Pacific Oceans ; a favorable feature which, with an excellent harbor on the Atlantic side, has always attracted the attention of those interested in the solution of the problem of interoceanic canal communication. The line has not been surveyed throughout its length, but from the partial examinations made by Mr. MacDougal, in the interest of Mr. Kelly of New York, in 1864, and by Commander Selfridge in 1871, its total

length has been approximately placed at 30 miles, of which from seven to ten miles will require tunneling.

Based on information obtained from these surveys, plans have been prepared for a canal at the level of the sea, the cost of which was estimated by the Paris Congress at $261 536 595, the tunnel having a section of 1 315 square yards and a length of 8.7 miles.

The main objection to this route is the long tunnel required to pierce the Cordilleras separating the two oceans, having an elevation of from 1 100 to 1 500 feet.

The available data is not sufficient to enable us to determine the probable cost of that work ; but it seems to be generally admitted, it will be so large as to exclude it from the number of practicable schemes, at least in a commercial sense. There is no doubt that great difficulties would have to be met in the opening of a tunnel of the dimensions proposed for ship navigation, and it seems to be equally true that almost all the plans suggested to overcome them have been based on assumptions as to the natural conditions. The limited knowledge we have at present of the geological formation of the isthmus has been gained from examinations of surface indications, deep wells, gold and silver mines, the excavations for a few railroads, at far distant points, and the banks and beds of streams. Some of the printed reports on the subject rest on mere superficial observations of only some of those sources of information. For example : a geologist accompanying one of the expeditions follows the *trail* of the surveyors for a distance of 10 or 12 miles, from the coast by the traverses, collects a few specimens of rocks and pebbles from the beds of the streams, takes some notes on the variable character of the soil and rocks cropping out here and there, and returns by the same way to tell us the *fact*, " that the Atlantic slope of the Cordillera in the vicinity of San Blas is composed of the older crystalline rock, such as granite, syenite and diorite, while that on the Pacific side belongs to the later eruptive period, and its rocks belong to the families of the trachyte and of the basalts, etc., etc." Had he gone but a few miles to the west he would undoubtedly have found at the head waters of the Chagres, deep gulleys or cañons cut in a continuous mass of soft lime stone ; and not far from there, blocks of trap rock and other varieties of stone, which might have somewhat modified his conclusions. Information so superficial as the above does not seem to " afford a sufficient guarantee that the rock to be met with in piercing a tunnel on the San

Blas route will, for the most part, prove to be of a character sufficiently homogeneous and firm to be self-sustaining," as has been assumed in computing the cost of a canal by that route. We have not the data to affirm that the contrary will be the case ; but the indications are, I believe, pointing to that conclusion, and the chances are, to say the least, just as much in favor of as against it.

The only way to arrive at the information required for the proper understanding of the subject, and to obtain the data for a fair estimate of cost, would be by sinking a number of shafts to the bottom of the canal on the line of the proposed tunnel. In this manner the character of the rock, and the quantity of water that would flow into the excavation when made, can be approximately determined. Boring with the diamond drill would show the character of the material to be met with, but would not furnish satisfactory information as to filtration. Until that is done the question may be considered as resting on mere *guessing*, in which the opinion of those who have been on the ground and gained information by actual observations should be entitled to most consideration. It is certain that in the construction of an isthmus ship canal at the level of the sea, it will be necessary to contend with water from filtration. This can be drained to the lower levels, while the bottom of the excavation is sufficiently high above the sea to allow the flow by gravitation ; but below that level the work will probably have to be done under water.

Pumping by different processes has been suggested as a means to overcome this difficulty, but the experience acquired from a close observation of what takes place in deep mines and in wells dug to a great depth, leads us to believe that such a recourse would be found altogether insufficient, even after dividing the tunnel by bulkheads into a number of small sections. Should these fears prove well founded, it will not be possible to approximately estimate the ultimate cost of such an undertaking. The Engineers of the first committee of the Paris Congress, of which Mr. Favre, the eminent engineer of the St. Gothard tunnel was a member, were of the opinion that such a contingency would increase the cost of the work by at least $20 000 000. In case the excavations below the level of the sea were carried under water, the men and machinery would have to work from scows, and the debris dredged and deposited in dumping scows to be disposed of at the ends of the canal : while all these operations of drilling, blasting, dredging and transporting would have, necessarily, to be done within a width of from 66 to 100 feet,

according to the dimensions proposed for the tunnel by different parties. Should it be found, as is apprehended by many, that the material met with is not self-sustaining and that the tunnel will have to be totally or partially lined with masonry walls resting on the bottom of the canal, the problem will become so complicated that a favorable solution may well be despaired of. That work would have to be done by underpinning from the crown of the arch, carried down to a depth of 28 or more feet below the surface of the water, and for a distance of several miles. By what methods it may be accomplished has not yet been explained. The advocates of a thorough cut are not disposed to admit that these contingencies are likely to be met with, and even deprecate the idea that the chances are just as much in favor of as against them. They will continue to base their estimates on the assumption that the waters from filtration will be no serious obstacle to the prosecution of the work to a depth of 28 or more feet below the level of the sea, as it may be readily disposed of by pumping ; that the material will be self-sustaining and sufficiently firm so that no lining of masonry, to speak of, will be needed to secure the stability of the tunnel, and that an inclination of one horizontal to ten vertical will be enough for the slopes of cuts 300 or more feet in depth.

From the above considerations it seems to follow, that the bottom of a canal across any portion of the Isthmus, should be placed sufficiently high above the sea to obtain natural drainage, and that without this condition the work may be considered impracticable on account of its immense cost. This modification involves the necessity of three or more locks on each side, which may not materially change the length of the tunnel, but is sure to considerably reduce its cost by the elimination of unknown quantities in this difficult problem.

The Nicaragua Route.

This line was carefully located from the Atlantic to the Pacific Oceans by the United States Surveying Expedition, under Commanders Hatfield and Lull, United States Navy, during the years 1872 and 1873, and is fully described in the official reports submitted to the Secretary of the Navy in 1873. I was Chief Engineer of these expeditions from the commencement of the surveys to the time the reports were completed, and have subsequently visited the country on three different occasions, and made extensive surveys in connection with this work, and the improvements of the navigation of the river San Juan. I have, in fact, given

close attention to the subject for a period of eight years. The estimates of cost were based on the data obtained from a line of actual location. Elevations of the ground were taken every 25, 50 or 100 feet ; and sufficient cross sections, soundings, and gaugings of streams, borings of the ground to the bottom of the canal, or until rock was met with, and such other additional information as to building materials and means of communication as were needed to arrive at a fair valuation of the probable cost were obtained. Nothing was taken for granted, in the formation of the project ; therefore, any changes of location introduced hereafter by a more detailed final survey, will, with perhaps one exception, reduce the original estimates.

This exception refers to the enlargement of all curves of less than 5 000 feet radius, objected to by some engineers, as too abrupt for a ship canal. Distinguished officers of the United States Navy were consulted as to the proper radii to be adopted, and they were of the opinion that 2 200 feet should be the minimum sufficient for the free passage of vessels 400 feet long. The following curves with the radii named were, in consequence, located, viz., 1 of 2 200 feet, 3 of 2 500 feet, 11 of 3 000 ; 1 of 3 500 and 3 of 4 000 feet ; all others have a radius of from 5 000 feet to 10 000 feet.

During the presentation of this route in the session of the 17th May of the Paris Congress, I was asked by M. Voisin-Bey, what, in my opinion, would be the additional expense involved in increasing the radii of the curves. I am reported in the printed proceedings of the Congress, as saying in reply, that $28 000 000 would be the probable cost demanded by the change. I do not remember what my answer was to that question, but it will be apparent to any one, that I could not have estimated so comparatively small additional work, at more than one-half the estimated cost of the whole canal. I believe that $1 800 000 would be a liberal allowance under the most unfavorable conditions. I have referred here to this subject because a writer in the *Bulletin du Canal Interoceanique,* a paper published in Paris, in the interests of the Panama scheme, has made a point of that evident typographical or reporter's error, and seems to doubt the accuracy of some of the figures embraced in the estimate of the Nicaragua route, which he could easily verify by computation from the elevations given in the profile of the line, and the cross-section recommended. He will also find in this paper an answer to his statements as to the cubical

amount of excavation required for both the Nicaragua and the Panama line. Lake Nicaragua, the proposed summit level of the canal, is 110 miles long by 30 miles wide, and is situated at $107\frac{63}{100}$ feet above the mean level of the ocean. Several trial lines were surveyed from the lake towards the Pacific, and on careful comparison of their relative merits and elimination, it was decided that those connecting the mouths of the little streams, Lajas and Del Medio, with the port of Brito, presented the greatest advantages on account of their moderate lengths and the comparatively low depressions by which they crossed the dividing ridge.

On a careful location, those lines were found to have an extreme length from the lake to the Pacific of 18.52 miles and 16.33 miles respectively for the Lajas and Del Medio routes. The divide was crossed at an elevation above mean high lake of 43.78 feet by the first and 134 feet by the second named lines. Considerations of better drainage and shorter distance decided us in favor of the Del Medio route, and the estimates of cost herein submitted are based on the data obtained from the survey of the same. The difference in their locations is comprised between the lake and a place called Las Serdas, where the level of the lake, if continued, would meet the Pacific Slope, thence to the Pacific, a distance of 8.33 miles, they form one and the same line. Should it be disclosed by a more detailed survey that the difficulties presented by the Lajas line for a good system of surface drainage can be overcome at a moderate expense, that would certainly be the most advantageous of the two, on account of a small extreme depth of cut through the divide and consequent reduced cube of excavation and cost.

The level of mean high lake is 103.14 feet above high tide at the port of Brito, an elevation to be overcome by ten lift locks 400 feet long between gates, 70 feet wide and 10.31 feet lift, located in a distance of eight miles. The depth proposed for the canal is 26 feet, and the width at the surface of the water 150 feet in earth and 106 feet in rock, with slopes of $1\frac{1}{2}$ horizontal to one vertical for earth and $\frac{1}{2}$ and $\frac{1}{4}$ horizontal to one vertical for rock.

The lake navigation extends from the mouth of the river Del Medio to Porto San Carlos, the head of the River San Juan, a distance of 56.5 miles. The river San Juan is proposed to be made navigable by means of four dams, and short canals and locks to pass them, for a distance of 63.02 miles to the confluence of the river San Carlos, the first large tributary of the San Juan. At this point the canal leaves the river, and

is located on its left bank for a distance of 26.90 miles, where it turns to the north, and by an almost straight line reaches Greytown, with a further distance of 15 miles, or a total length of 41.90 miles from the point where it leaves the river at San Carlos. This river it is proposed to divert, so that its discharge into the San Juan shall be below the last dam, and thus keep out of the canal its muddy and silt bearing waters. Ten lift locks of 10.87 feet lift are estimated for this side, three of which are located on the short canals around the dams.

The following table will show the position, and length, height, and other particulars of the dams :

Location.	Distance from Lake, in miles.	Length of Dam, in feet.	Height above bottom of River, in feet.	Height water is raised in front of Dam, in feet.
1. Castillo	37.34	940	21.01	18.87
2. Balas	44.69	1 196	31.92	22.82
3. Machuca..............	50.57	824	33.99	26.84
4. San Carlos..............	66.81	1 000	30.97	23.87

The first three dams rest on rock foundation and rocky abutments. The last one will rest on a hard and compact gravel bottom, and is intended to be protected by an apron to prevent the undermining effect of the fall. They are designed to be built of concrete, and so constructed that the water in the river will not be raised until the structures are completed in all their parts. This is expected to be accomplished by leaving sluices in the dams sufficiently large to afford a free passage to the river at high water, and to be closed by suitable gates on the upper sides when the dam is ready to receive the pressure intended. The river will be backed to the lake, the surface of which will be raised from three to four feet, and I estimate that it will take about four months for the river to reach the top of the first dam.

In the meantime the openings in the dams may be closed from the lower side, and the material will have sufficient time to set, before it is brought in contact with the water.

This method of construction will have other advantages in the construction of the canal.

It will permit the dredging and rock excavations under water to be done at a moderate depth, and allow the construction of the short canals and lift locks around the dams, free from the high water of the river.

The total length of the line from Greytown, on the Atlantic, to Brito, on the Pacific, is 181.26 miles, divided as follows :

INLAND CANAL.

	Miles.
From the mouth of river Del Medio, at the lake, to Brito..............	16.33
Short canal around Dam No. 1 across the river San Juan..............	0.78
Short canal around Dam No. 2 across the river San Juan..............	1.57
Short canal around Dam No. 3 across the river San Juan..............	1.16
From Dam No, 4, below the river San Carlos, to Greytown.............	41.90
Total length of canal................................	61.74
Lake navigation.......................................	56.50
Slack water navigation by the river San Juan,.......................	63.02
Total miles...	181.26

The following is a recapitulation of the estimated cost, viz. :

WESTERN DIVISION.

From the mouth of the River Del Medio to Brito, 16.33 miles.

Excavation and embankment....................................	$16 787 566
Ten lift locks, 400 feet by 70 feet by 10.37 feet lift...................	3 957 818
One tide lock, 400 feet by 70 feet by 9.00 feet lift....................	421 306
Drains, grubbing and clearing, &c................................	514 087
Total for Western Division...............................	$21 680 777

Middle Division, or lake navigation, 56.50 miles.

Dredging in mud and gravel and excavation in rock................	$715 658

EASTERN DIVISION, FROM THE LAKE TO GREYTOWN.

Slack water navigation, 63.02 ; Inland Canal, 45.41 = 108.43 miles.

Excavation and dredging in the river.......................	$5 076 030
Short canals around dams.....................................	1 056 922
Excavation and embankment in canal, from Dam No. 4 to Greytown,	13 389 398
Dams Nos. 1, 2, 3 and 4.................................	1 543 526
Lift locks, from 1 to 10, inclusive.	3 093 160
Drains...	340 400
Diversion of San Carlos river.................................	283 578
Grubbing and clearing (2,379 acres)	237 900
Total for Eastern Division...........	$25 020 914

RECAPITULATION.

Western Division.............	$21 680 777
Middle or Lake Divison...	715 658
Eastern Division.........	25 020 914
Harbor of Brito......... ....,......	2 337 739
Harbor of Greytown .... ,.................	2 822 630
Total	$52 577 718
Add 25 per cent. for contingencies	13 144 429
Grand total.................................	$65 722 147

There are about 10 807 cubic yards of rock excavation estimated for, at the west side of the Lake, which would have to be blasted and dredged out at a depth of twenty-six feet below the level of the water in the canal or twenty-two feet under water in the lake, at the time of doing the work. This has been estimated for at $5.00 per cubic yard, which is thought a liberal price, considering that the rock is not a hard solid mass, but boulders and blocks. Col. Childs' estimate of the same work in 1851, when our present means for doing this kind of work were unknown, was from $2.50 to $5.00 per cubic yard. There are also 834 992 cubic yards of rock excavation, and dredging in the river at depths varying from nine to fourteen feet, which has also been estimated for at $5.00 per cubic yard. Much of this material is loose rock, and the whole would be removed before the river is raised by the dams.

The actual cost of some rock excavation in the River San Juan, at a depth of six feet, done recently on a small scale and with scanty means at hand, has been $2.50 per cubic yard of rock deposited on the banks ; and I have been told by Mr. A. C. Rand of New York, that rock blasting and dredging to a great depth (from sixteen to twenty-four feet,) is now being done in the River St. Lawrence, at a cost of less than $5.00 per cubic yard.

The total amount of excavation, dredging and embankment, exclusive of the harbors estimated upon, may be given as follows:

Excavation in earth, cubic yards................................	32 433 797
Excavation in rock, cubic yards....	14 435 477
Dredging in the lake and river........	4 855 935
Embankment	7 262 629
Excavation in rock under water...........	845 719
Total cubic yards................................	59 833 557

Deducting from this total cube the embankment which will be constructed with the material proceeding from the excavation, at a small additional expense over that for transportation, we will have 52 570 929 cubic yards as the total amount of excavation and dredging required, or 45 800 000 cubic yards less than the computed volume for the Panama Canal, *a niveau*, with the same slopes and cross-section.

Computing the cubical contents according to the cross-sections proposed for open cut, and a bottom width for the channel in the lake and river of 100 metres (328 feet), as recommended by the Paris Congress, we obtain a cube of earth and rock work of 53 793 982 cubic metres, or 70 663 000 cubic yards, an increase in the total amount of 10 947 998 cubic yards, as shown in the following table :

CUBICAL CONTENTS OF EXCAVATION IN CUBIC YARDS.

	With Cross Section of Paris Congress.	With Cross Section for Nicaragua Line.	Increase.	Decrease.
Excavation in earth........................	31 535 500	32 433 797	....	898 297
Excavation in rock..............	10 393 537	14 435 477	....	4 041 940
Dredging in the river and lake...........	18 209 722	4 855 935	13 353 787	
Excavation in rock under water...........	3 380 167	845 719	2 534 448	
Embankment......	7 262 629	7 262 629	....	
	70 781 555	59 833 557	15 888 235	4 940 237

This increased amount of excavation is due to the enlargement of the bottom width of the channel in the lake and river from 80 to 328 feet. The width of 80 feet at the bottom of the channel, with slopes of six horizontal to one vertical, I consider ample for all practical purposes. In fact, a vessel drawing 24 feet would have a channel of 104 feet in width, and for one drawing 20 feet the width would be 152 feet. I cannot see why the channel in the river and lake, if properly marked, should be much wider than in the inland canal, inasmuch as there is no perceptible current in the lake, and that in the river will not exceed one mile per hour after the improvements are completed.

I had occasion to call the attention of the first sub-committee of the Technical Commission to the increased cube of dredging and rock excavation under water, as herein, given, and suggested that by raising the

height of the first dam across the river San Juan one metre (3.28 feet), more than two-thirds of the amount of excavation and dredging could be dispensed with ; and also, about 360,000 cubic yards of rock excavation between the lake and the Pacific. This change was not proposed in the original project, because it involved an increase of 3.28 feet in the elevation of the summit level. This would not be justified by the small saving resulting therefrom.

The objections made·to this route are: lift locks indispensable to the solution of the problem, length of route, and poor harbors at either end.

A canal without locks, that is, at the level of the ocean, is, no doubt, a great *desideratum*, but its cost, under the most favorable circumstances, would be so great as to place it beyond the possibilty of a successful commercial enterprise. The work, if ever done, will be undertaken by private initiative and private capital, and these are not likely to embark in an undertaking which does not promise sure and liberal returns, however beneficial it may be to the world at large, and however great a monument to mark the present age. Under the circumstances, therefore, recourse must be had to locks, which, if properly constructed and sufficiently supplied with water, will be found less objectionable than has been supposed, The objections to locks are: loss of time in passing through, and liability to accidents. With a moderate number of them, properly constructed, the first objection will be found to be of little consideration, and is surely to be compensated for by the smaller tolls charged in proportion to the reduced cost of the work, as compared to other routes.

In pursuance of the system adopted in the design and computation of this project. of not introducing doubtful elements in the whole or any of its parts, the lift of the locks was fixed at 10.37 feet on the Pacific side, and 10.87 feet between the lake and the Atlantic. All of them have been located so that they will rest on rock or stiff dry clay foundations, and there seems to be no good reason why their lift should not be increased to 15 feet, thereby reducing their number to fifteen.

The ground certainly offers all the facilities that could be desired for the change. The engineers of the Paris Congress fixed the lift at 4 metres (13.12 feet) and the number of locks at seventeen.

General Weitzel, U. S. A., is now constructing a lock on the St. Mary Falls Canal of 525 feet between gates, 80 feet wide and 18 feet lift. Through this lock he proposes to pass a ship in 11 minutes, as follows:

Entering lock.. 1½ minutes
Closing gates... 1 "
Filling lock.. 6 "
Opening gates... 1 "
Leaving lock.. 1½ "

　　　　Total...11 minutes.

The locks I have designed for the Nicaragua Canal would admit passage to a vessel in about 20 minutes, a time which can be much reduced by enlarging the feeding and draining conduits.

I have the authority of Sir John Hawkshaw for stating that from 15 to 20 minutes would be ample time to pass a lock of the dimensions required for the canal, and the latter time has been adopted as a mean.

As to the liability to accident, it seems to me that, if properly constructed, and intelligently worked, no apprehension should be entertained in that respect. Surely no such objections have been met with in the dry docks in universal use, nor in the large canal locks in operation in this country and others that might be named. There are, on the other hand, certain advantages possessed by a canal with locks over one at the level of the sea ; for example, all, or the greater portion of the work can be completed before the water is admitted into the canal ; any portion of the canal can be partially or entirely drained into the lower levels to allow an examination or facilitate repairs in the channel or locks ; a perfect system of drainage, independent of the canal, can be obtained for the adjacent water sheds, and thus prevent floods from doing injury to the canal. On the Nicaragua line, for instance, all the locks on the Pacific slope, except the lower two, can be drained into the Rio Grande, and similarly some of those on the Atlantic side.

The objection as to the length of the route may be answered by a reference to the statements of distances given before.

It may be seen that the total length of canal navigation is 61.74 miles, and there is no reason why a steamer should not travel in the lake and river with her usual speed at sea.

The estimated time in passing by steamer, from ocean to ocean, is as follows :

　　62　miles of canal, at 4 miles an hour..................15½ hours.
　　63　miles of river navigation, at 6 miles an hour........10½ "
　　56½ miles of lake navigation, at 10 miles an hour........ 5½ "
　　21　locks, at 20 minutes each......................... 7 "

　　　　Total...38½ hours.

Artificial harbors will have to be constructed at either end of the canal. Plans and estimates have been prepared for the same, and they have received the approval of many distinguished engineers, and were accepted by the Paris Congress without criticism. It has been determined by careful observations that the sand bank obstructing the entrance to the harbor of Greytown has been formed by the action of the sea striking the sandy beach at an angle. It is proposed to construct a breakwater or jetty, that, acting as a trap, will intercept the sand moving along the coast from east to west. A channel will then be dredged, under the lee of the jetty, to obtain an entrance to the bay, the latter to be sufficiently deepened by dredging to satisfy the demands of traffic.

At Brito, a breakwater, a pier, and dredging will be required to build a harbor large enough to secure a smooth entrance to the canal, and accommodate a number of vessels. With the lake, only 16 miles from the sea by the canal, possessing all the advantages of an excellent internal harbor capable of accommodating all the fleets of the world, the harbor of Brito need not be large.

Building materials of all kind, such as wood, lime, stone, sand, etc., can be obtained in great abundance, either on the line of the canal, or at a convenient distance from it. With the river San Juan, the two lakes and the river Tipitapa, which can be made navigable for vessels drawing six or eight feet at a small expense, an easy and inexpensive line of communication may be established through almost the whole extent of the country by which men, provisions and materials can be transported to any point along the proposed canal, from Greytown to and through the lake, and from the west coast of the latter to the Pacific, a distance of 16 miles, a railroad can be constructed at a small cost, or the present cart roads can be extended and improved so as to answer the purposes intended.

Sufficient data have not been obtained to determine the annual mean rain-fall of Nicaragua for a number of years ; but, from the observations of Col. Childs in 1851, those of the surveying expeditions in 1872 and 1873, and the records of the College of Granada for the year 1875–1876, we approximately fix at 52 inches on the Pacific slope, and 85 inches on the Atlantic side.

The watershed of Lake Nicaragua is 12 250 square miles, which includes the area of the lake itself, 2 700 square miles. Its outlet, the

river San Juan, has a discharge of 12 453 cubic feet per second when at its lowest stage in the month of May, and at high water the discharge is 20 500 cubic feet per second, these being the flow above the point where the canal leaves the bed of the river, to be located on its left bank, and thence to Greytown. Below the point referred to, the flow is considerably increased by the accession of the waters of the rivers San Carlos, Serapiqui, and other tributaries. Below the Serapiqui the flow is about 22 200 and 55 500 cubic feet per second in the dry and rainy seasons respectively.

The Colorado branch of the river San Juan carries to the sea no less than $\frac{29}{30}$ of the volume of the San Juan, leaving but $\frac{1}{30}$ of the flow to discharge into the harbor of Greytown by the lower San Juan. Many have suggested to close the Colorado by a dam, and thus throw the whole volume of the river into the harbor as a means of scouring it out and keeping its entrance open, but this plan has been thought, after much consideration of the subject, to be impracticable and inefficient.

Earthquakes are rather frequent in Nicaragua, but are only slight shocks that never have done any injury to life or property, nor altered in the least the level of the waters in the lakes, rivers, wells, etc. Works built by the Spaniards over one hundred years ago, such as masonry dams across rivers, fortifications, indigo vats, cisterns and the like, are to-day in an excellent state of preservation.

Conclusion.

From the above statements and considerations it seems to follow—

1st. That however desirable a canal at the level of the sea, partaking of the nature of a strait may be, to better satisfy the demands of trade, its execution, either with or without a tunnel, presents so many difficulties and doubtful elements as to place its probable cost out of the range of a successful commercial enterprise.

2d. That a canal with locks can be so constructed as to satisfy all the requirements of ocean navigation, at a cost within the possibility of a private undertaking, with reasonable expectations of liberal returns and without overtaxing the commerce of the world intended to be benefited thereby.

3d. That while a canal with locks seems to be practicable, *via* both Panama and Nicaragua, the latter route possesses greater facilities for the execution of the work at a reduced estimate of cost based on suffi-

cient information to eliminate unknown elements, which might materially so alter the conditions of the project, as to cause painful disappointment to take the place of long deferred hopes and cheering expectations.

And furthermore, that the geographical position of Nicaragua is more favorable to the United States, whose commerce will contribute more than that of any other nation to the business of the canal, while it will afford as great commercial advantages to foreign nations, as other routes more to the south.

Finally, I would state that, while attempting to confine my remarks upon this interesting subject (upon which volumes have been and may yet be written) to as limited a space as possible, I have treated it more at length than was originally intended, and close with the hope that conciseness, if at all attained, has not been at the sacrifice of clearness in the presentation of the points touched upon.